"Breathing" coal mines and surface asphyxiation from stythe (black damp)

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That disused coal mines "breathe" is well recognised within the mining industry, though the surprisingly close parallel with mammalian breathing may not be so widely appreciated. By contrast, the effect on surface communities living in the path of the expired mine air seems to have attracted scant attention.

Though access shafts are often sealed when a coal mine is abandoned, the airways within the mine may remain patent, depending on the degree of subsidence, and a substantial volume of alveolar air (potentially as much as 500 million litres per km^2 of shallow mined seam) may retain immediate contact with exposed coal faces, tunnel walls, and pit props. This allows metabolic oxidative processes to continue, thereby removing oxygen and replacing it (partially) with carbon dioxide. The process would be self limiting in the absence of ventilation, but some mines are connected by geological pores of Kohn to a natural positive pressure respirator—the earth's atmosphere.

At times of stable weather and high atmospheric pressure fresh air is forced into these mines with a tidal volume which may reach several million litres per km^2, thereby allowing tissue respiration to continue. As atmospheric pressure returns (fairly quickly) to normal the mine expires a similar volume, which consists of its alveolar air mixed with the recently inspired fresh air. Such a mixture may pose little hazard, but when weeks or months later there is a storm and a rapid and profound fall in atmospheric pressure the mine may expire undiluted alveolar air with a dangerously low oxygen content at a forced expiratory volume in one second of several hundred litres per km^2. This alveolar air is known locally in north east England as stythe or stythe gas but is more generally called black damp or choke damp—a reflection on the occupational threat it has posed to generations of coal miners. Far less commonly it may threaten overlying communities if it accumulates under impervious layers of rock or clay and then finds access to a limited area on the surface through fissures or faults. Such an event occurred recently in Newcastle upon Tyne.

Case history

A 42 year old woman moved into her newly purchased home in a former mining area on 27 March 1987 in heavy rain. The house had been vacant and closed up for two or three days. Subsequent experience showed that it was well insulated and hence was probably well "sealed." Once she and her helpers had deposited her belongings indoors she discovered that neither her cigarette lighter nor her gas fire would work. She began to feel dizzy and nauseated and became a little unsteady walking. A rare tension headache followed and she felt that there was an "atmosphere" (but no distinctive odour) in the house. Her helpers reported similar symptoms and despite the rain opened all windows and went outside. Their symptoms passed within a few minutes.

Suspecting a gas leak, she summoned a gas board engineer. He found no evidence of leaked mains gas or loss of pressure and could light both cigarette lighter and fire. She thought no more of the matter, slept upstairs with opened windows, and continued to feel normal next day. Over the next six months, however, she estimated there were a further 15 or so occasions when similar symptoms recurred—both in her and in visitors. There was no obvious pattern relating these to her occupational or domestic activities, but she noted a relation with bad weather.

Her son then suggested that toxic gases might be diffusing into her home from underlying disused coal mines, a suggestion she passed on to the Mines and Quarries Inspectorate. An inspection failed to detect any excess of natural gas, carbon monoxide, or methane, but oxygen was found to be deficient. As a result she entered a prolonged dialogue with officials from the inspectorate, the National Coal Board, and local civic authorities, and an equally prolonged period of monitoring oxygen and carbon dioxide concentrations began.

She also learnt of a curious and more widespread incident that had occurred on the day of her house move. In a neighbourhood of some 150 households 3-5 km away there had also been considerable difficulty with lighting gas appliances.[1-3] The gas board, initially fearing a major mains leakage with pressure loss, organised an evacuation, which led to the discovery of an elderly couple who had apparently been overcome after entering the cellar of their home[1 4] They recovered fully. Leakage of mains gas was quickly excluded but low oxygen concentrations with high concentrations of carbon dioxide confirmed there had been a major escape of stythe. It transpired that an unusually large fall in atmospheric pressure had occurred on 27 March 1987 and that other stythe escapes had been documented in the area two, six, and 30 years previously. The underlying mine had closed in the early 1940s.

MONITORED LEVELS OF OXYGEN AND CARBON DIOXIDE

Oxygen and carbon dioxide concentrations were measured repeatedly by officials from several organisations (particularly the National Coal Board) and continuously recording devices were left in the patient's house for her to read. Clear advice was given to evacuate the premises in certain circumstances, and this was duly followed on four to six occasions. Documents from all the various sources showed a consistent pattern. Oxygen concentrations within the patient's home were noted to reach extraordinarily low troughs of 8-9% in a cupboard under her kitchen sink, exposures which would rival those near the summit of Mount Everest. It was concluded that the most relevant portal of stythe entry was the underlying defect in the cement floor through which water pipes entered and left the building. Elsewhere concentrations varied from normality (mostly) to transitory lows of about 12% in confined downstairs sites such as

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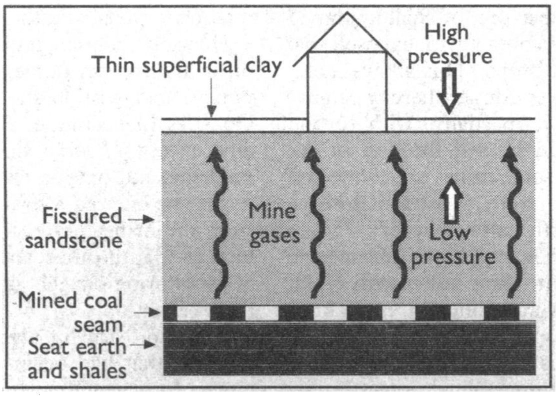
cupboards. Some living areas gave occasional values in the range 16-19%. The maximum concentration of carbon dioxide was recorded as 7·05%. In homes of the affected community nearby oxygen concentrations as low as 13-15% were measured at times of rapidly falling barometric pressure.

In an attempt to divert the flow of stythe around the patient's home a shallow venting shaft was sunk into the adjacent soil. Samples from this gave a minimum concentration for oxygen of 9·85% and a maximum concentration for carbon dioxide of 9·4%. Amounts of natural gas, carbon monoxide, and methane were negligible throughout.

GEOLOGICAL FEATURES

The figure illustrates the critical geological features responsible for the intermittent release of stythe into the patient's home. A layer of fissured sandstone overlying the mined coal seam permitted diffusion of stythe towards the ground surface. A fault near the patient's house locally increased the fissuring and fracturing. A layer of impervious superficial clays over the sandstone prevented a diffuse loss of stythe from the soil surface and channelled its discharge through an area where the superficial clays were relatively thin.



Critical geological features responsible for intermittent release of stythe into subject's home

The patient's house (which was at the edge of an estate) overlay not only the geological fault but the thinner superficial clays, which may have been breached by the builders, thus limiting the worst effects on this particular estate to the patient's home.

OUTCOME

The shallow venting shaft in the patient's garden was not successful, and the National Coal Board eventually sank new shafts into the mine in order to ventilate it mechanically. Subsequent air flow rates through the mine were evidently adequate to dilute and dissipate ongoing stythe production, and all subsequent measurements of oxygen and carbon dioxide concentrations in affected homes were normal.

Comment

The coal mining industry is well aware of stythe and the potential hazard it may pose to surface communities. The knowledge acquired is readily available, and local newspapers were quickly able to report the events described with clarity and accuracy.[1-5] It is therefore surprising that respiratory and occupational physicians are largely unaware of this interesting environmental risk from coal mining. It has similarities to a recent, more natural and more calamitous event in Cameroon, when a massive volume of carbon dioxide released from a stagnant lake was thought to have been responsible for suffocating as many as 1700 inhabitants of an adjacent village.[6]

Cases of severe asphyxiation associated with stythe have not been reported in surface communities, so the level of risk does not seem to be high—that is, provided exposure is not encountered in confined, low lying, and poorly ventilated spaces where "heavy" carbon dioxide is slow to dissipate (for example, cellars). Fatal asphyxiation has occurred when wells have been entered during periods of falling barometric pressure, simply as a consequence of the outflow of oxygen depleted gas from surrounding porous strata.[7] Any organic matter present within such strata will undergo oxidation and decomposition, thereby producing stythe, and it seems that even within coal mines much of the stythe produced may be a consequence of decomposition of timber (pit props) rather than coal oxidation.[8] The effect of pit acids on carbonate minerals may provide a further source for the carbon dioxide content.

Successive closure of other local mines may also have been of relevance in this particular coal field. Much of it is interconnected, and it is only when a wide area is totally abandoned that there is no longer any need to pump out seepage water. Once pumping stops water levels rise and stythe from deeper levels is displaced towards the superficial seams—on occasions in large volumes, when pockets of high pressure are suddenly released.

"Mature," undiluted stythe contains little or no oxygen, yet the carbon dioxide concentration varies considerably from pit to pit in a reciprocal relation with nitrogen.[7,8] Apparently timber releases rather more carbon dioxide per unit volume of extracted oxygen than coal, so different symptoms are to be expected when different stythe and air mixtures are encountered. When the concentration of carbon dioxide exceeds 3% ventilation is stimulated; with higher concentrations respiratory distress dominates the clinical picture together with skin flushing and headache. Anoxia is usually better tolerated, and miners' lamps of yesteryear would become extinguished (at oxygen concentrations <17%) long before a relatively undistressing loss of intellectual function and impaired muscle control occurred in the miners themselves.

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